PREDICTION OF SEDIMENTATION AND BANK EROSION DUE TO THE CONSTRUCTION OF KAHANG DAM

Muhammad Nda

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DEDICATION

To the Almighty Allah, for sparing our lives and providing the wisdom and guidance to carry out this study.

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ABSTRACT

River impoundments continue to cause changes to the hydrological regimes of its host river. Thus, assessment and development of tools for better understanding of the sediment dynamics and riverbank erosion downstream the dam will be of great benefit to researchers and policymakers. The present research employs the use of field techniques and estimation models to improve the (i) prediction of suspended sediment concentration, (ii) monitoring riverbank erosion, and (iii) development of Riverbank Erosion Index (R_bEI) for downstream Kahang Dam. This research used the Artificial Neural Network (ANN) and ANN with Autoregressive (AR) (NNETAR) in predicting suspended sediment concentration using sediment concentration, discharge and water level as inputs. Similarly, erosion pins were installed on four transects to monitor the riverbank for thirteen months. The results obtained for sediment concentration prediction clearly show that the R^2 for NNETAR (0.885) have better value compared to ANN (0.695) even though the relationship between discharge and sediment concentration was weak, it outperforms the ANN. While based on the sediment rating curve (SRC) results, the same pattern was exhibited where the R^2 for NNETAR show a greater value than ANN and SRC with R^2 values of 0.695 and 0.451, respectively. Based on the observed results of quantified riverbank erosion, the most active transect eroded 1.747 mm/yr^{-} while 0.657 mm/yr^{-} is the least eroded. furthermore, the result reveals the maximum and minimum sediment contribution to the fluvial system from riverbank eroded to be 0.00743 tonnes/yr and 0.00148 tonnes/yr respectively. Lastly, by using discharge and percentage soil composition (sand and clay), a R_bEI was developed by the adopted Equation 4.7 to estimate the status of riverbank erosion of River Kahang. Moreover, five classifications of erosion status were proposed, which can be used to describe the status and severity of the riverbank erosion. In conclusion, the estimates by the R_bEI is expected to serve as basis for analysing and adopting river stabilisation and restoration design, which will be of importance to dam operators in making informed decisions regarding early warnings on the riverbank stability. Also, reliable sediment concentration estimation will assist in the development of catchment sediment budget which will give an insight into the effect of situating a dam on a river in terms of sediment supply and riverbank erosion

ABSTRAK

Kerja pengempangan sungai akan menyebabkan perubahan kepada regian hidrologi. Oleh itu, proses penilaian dan pembangunan kaedah pengukuran bagi menentukan kadar perubahan sedimen dan hakisan tebing sungai amat diperlukan bagi meningkatkan tahap kefahaman penyelidik dan penggubal dasar. Kajian ini dijalankan dengan menggabungkan data yang dikumpul di lapangan dan model anggaran untuk meningkatkan (i) ramalan kadar enapan terampai di kawasan kajian, (ii) pemantauan hakisan tebing sungai, dan (iii) pembangunan Indeks Hakisan (R_bEI) bagi kawasan hilir Empangan Kahang. Rangkaian neural buatan (ANN) dan ANN dengan *autoregressive* (AR) (NNETAR) digunakan untuk meramalkan kepekatan enapan terampai kawasan kajian dengan menggunakan data kepekatan enapan, kadar alir, dan paras air sebagai data masukkan utama. Begitu juga, pin hakisan telah dipasang di empat transek bagi memantau hakisan dan pemendapan di tebing sungai selama tiga belas bulan. Keputusan ramalan kadar enapan secara jelas menunjukkan nilai R^2 NNETAR (0.885) adalah lebih baik dibandingkan dengan ANN (0.695) walaupun hubungan diantara kadar alir dan kadar enapan adalah lemah, tapi ia lebih baik dari ANN. Sementara itu, berdasarkan keputusan lengkung kadar enapan (SRC), menunjukkan bentuk yang sama di mana nilai R^2 bagi NNETAR adalah lebih besar dari ANN dan SRC dengan nilai R^2 masing-masing adalah 0.695 dan 0.451. Berdasarkan kepada keputusan pemantauan kadar hakisan tebing, transet yang paling aktif terhakis ialah 1.747 mm/tahun manakala 0.657 mm/tahun sebagai kurang terhakis, Tambahan pula, keputusan juga menunjukkan kadar enapan maksimum dan minimum yang terhasil dari proses hakisan tebing sungai kedalam sungai adalah 0.00743 and 0.00148 ton/tahun. Akhir sekali, dengan menggunakan data kadar alir dan peritus kandunan (pasir dan tanah liat), a R_bEI telah dibina dengan menggunakan persamaan 4.7. untuk mengangarkan keadaan hakisan tebing bagi Sungai Kahang. Selain itu, lima klasifikasi jeni hakisan telah dicadangkan yang boleh digunakan untuk menerangkan berkaitan keadaan dan keterukan hakisan tebing, Kesimpulannya, anggaran nilai oleh R_bEI di jangka akan menjadi asas dan di adaptasi untuk rekabentuk stabiliti dan pemulihan sungai yang akan menjadi penting kepada pengendali empangan untuk memaklumkan lebih awal kepada pemegang taruh berkaitan dengan kestabilan hakisan tebing. Selain itu, kebolehpercayaan anggaran nilai kadar enapan akan membantu di dalam pembinaan tempat tadahan enapan yang akan memberikan kesan kepada kedudukan empangan dari segi kadar enapan dan hakisan tebing sungai.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	Cross-sectional area
ANN	Artificial Neural Network
AR	Autoregression
B	Channel width
BR	Bayesian regulation
CART	Classification and Regression Tree Algorithm
CC	Correlation coefficient
d	Channel depth
EF	Efficiency Factor
R_bEI	Riverbank Erosion index
FFBP	Feedforward Backpropagation
FFNN	Feedforward Neural Network
Fr	Froude number
GEP	Gene Expression programming
GRNN	Generalized Regression Neural
GSD	Grain size distribution
HDFNN	Hybrid Double Feedforward Neural Network
KGE	Kling – Gupta Efficiency
LIDAR	Light detection and ranging
LM	Levenberg-Marquardt
MAE	Mean Absolute Error
MLP	Multilayer Perceptron
MLR	Multiple Linear Regression
MUSLE	Modified Universal Soil Loss Equation
NNETAR	Artificial Neural Network & Autoregression
NS	Nash-Sutcliffe coefficient
PBIAS	Percent Bias
PCA	Principal Component Analysis
PEEP	Photo Electronic Erosion Pins
Q, Qw	Discharge
RBF	Radial Basis Function
RE	Absolute Error
RMSE	Root Mean Square Error
RSR	Observation standard deviation ratio
RUSLE	Revised Universal Soil Loss Equation
SCG	Scaled Conjugated Gradient

SI	Scatter index
SSC	Suspended sediment concentration
SSL	Suspended sediment load
SRC	Sediment rating curve
St1,St2,St3	Station one, Station two, Station three
U	Average velocity
USLE	Universal Soil Loss Equation
V	Velocity
WANN	Wavelet Artificial Neural Network
USLE	Universal Soil Loss Equation

CHAPTER 1

INTRODUCTION

1.1 Background

Riverbank erosion results from a complex interaction arising between the riverbank physical characteristics and the hydraulic conditions of the channel, both of which are variable (Varouchakis *et al*., 2016). Riverbank erosion is a natural geomorphological process that affects the fluvial environment in many aspects: physical, ecological and socio-economic. The process is also considered important from the geomorphological aspect as it stimulates adjustments in the river channel course and the development of the floodplain (Castro-Bolinaga & Fox, 2018). Riverbank erosion process consists of three primary mechanisms, subaerial process, mass wasting and fluvial erosion, which is driven by different soil properties that are spatially variable. The wetting and drying cycles, freeze/thaw cycles and several other processes responsible for weakening the riverbank soil particles are known as subaerial processes (Couper & Maddock, 2001). The occurrence of imbalance between the forces responsible for resisting erosion and gravitational forces acting on a riverbank results to mass failure or gravitational failure.

Fluvial erosion is a continuous process whereby hydraulic forces remove soil particles from stream flow. The physical, geochemical and biological properties of soil particles are known to influence the fluvial erodibility parameters (Grabowski, Droppo & Wharton, 2011). The particle size of soil is a vital factor when considering soil erodibility. In the case of cohesive soils, higher levels of cohesion are due to a corresponding higher concentration of clay-size particles, which improves the soil resistance to erosion (Grabowski *et al.*, 2012). The erosion rate is enhanced through channel modification due to river damning, vegetation and riparian removal along the river corridor, gravel extraction, high rate of overland runoff, increased impervious surface runoff, seasonal precipitation rates, frequency and duration of storm events and several other environmental alterations (Ghosh, Pal & Mukhopadhyay, 2016).

Water and wind are highlighted as common agents of erosion by previous researchers. Water is considered in many parts of the world as the most prevalent cause of soil erosion compared to wind. Malaysia with mean annual rainfall exceeding 2000 mm has a comparatively hot and humid weather condition throughout the year due to its tropical rainforest climate and therefore identified to be susceptible to erosion (Zainal Abidin, Sulaiman & Yusoff, 2017).

Sharifah, Al-Toum & Jaafar (2003), suggests that accelerated soil erosion is endemic throughout the humid tropics, but little is known of the dynamics and occurrence rates of sediment concentration and erosion rates in Malaysian rivers even though previous studies have been carried out in the area. Furthermore, they confirmed that most of the eroded material from the soil enters the river system as suspended sediments. For instance, the mean suspended sediment concentration in rivers in Malaysia due to soil erosion raised by 34% in 1998 which cause degradation of water quality while siltation of these suspended sediments in the river caused a transformation of channels from natural to urban conditions.

Riverbank erosion is considered a significant source of sediment contribution to rivers and stream. Previous research reveals that one of the primary sources of riverbed material is from sediment eroded from riverbanks and in some instances accounting for more than 80% of the total sediment load. Also, degraded banks constitute a substantial contributor in river nutrient loading, the contribution of eroded sediment to total phosphorus loading in small catchments is estimated between 40% and 47% (Fox, Purvis & Penn, 2016; Palmer *et al.*, 2014). Sediment is naturally transported in streams in a specific amount, but human activities are responsible for enhancing overall erosion rates thereby increasing the amount of sediment delivered to rivers and other water bodies (Knox, 2006; Rosgen, 2001).

Dams are most times regarded as one of the most leading forms of human impact on the fluvial system in changing sediment and flow regime of rivers. Decrease flux of water and sediment is caused by dams resulting in changes downstream and upstream the dam, i.e., downstream degradation or upstream aggradation respectively. River systems hosting series of dams exhibit more complex situation due to response processes emanating from the different system sections (Poeppl *et al*., 2013). The geomorphic response to changes in sediment supply can cause series of channel adjustments including; slight textural adjustment of the riverbed particle size distribution, changes in in-channel sediment storage, channel planform changes, i.e. incision or widening to complete channel pattern change from braided to meandering or inversely. It is difficult to ascertain the exact sediment supply shortage that will trigger this series of responses as well as the sequence of the responses (Grant, Schmidt & Lewis, 2003). However, the general trend and directions are well established and illustrated in Figure 1.1.

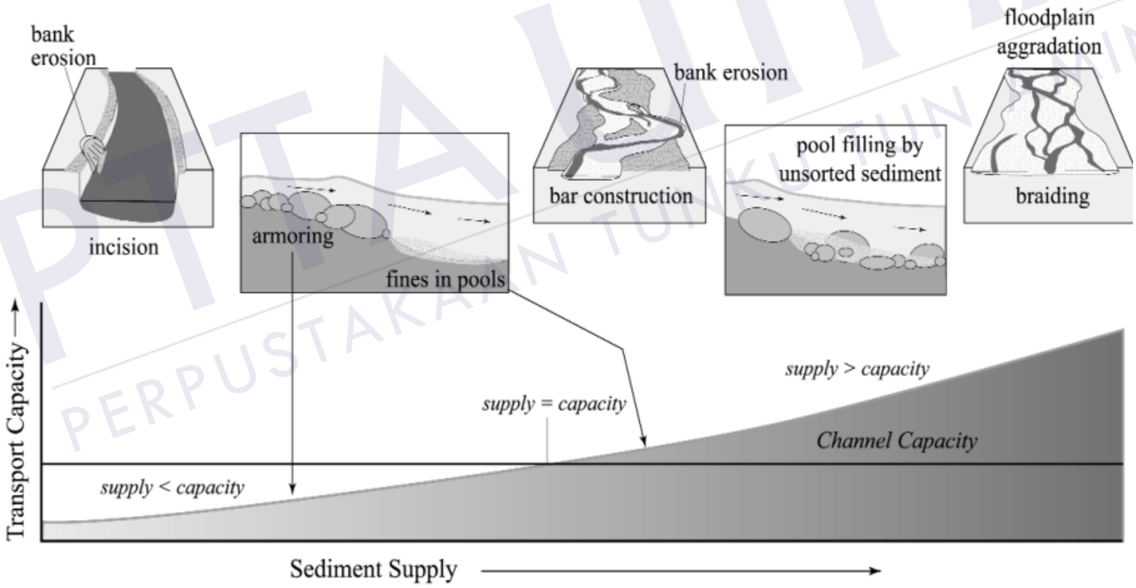

Figure1.1: Channel adjustment of alluvial rivers in response to altering sediment supply concerning transport capacity

Source: (Grant *et al*., 2003).

Assessing geomorphic adjustments along river corridors is commonly an essential component of developing catchment and surface water management strategies. The riverbank erosion rate is a means of direct measurements of fluvial geomorphic change that can be employed to evaluate river corridors. Riverbank erosion can represent a substantial portion of the total sediment and nutrient, i.e. nutrient loading to river systems (Foucher *et al*., 2017), it is therefore essential to quantify. Riverbank erosion and channel change measurement are also vital in understanding the geomorphic condition of a river system. Besides, monitoring riverbank erosion presents an opportunity in understanding its risk to infrastructure and stream habitat posed by fluvial erosion (Thakur, 2014).

1.2 Problem statement

Dam construction is currently one of the most critical influences on land-ocean sediment fluxes (Kummu & Varis, 2007). Regulation of flow by dams is known to substantially alter the pattern of rivers and streams due to confined water release situations and through a significant reduction in sediment transported downstream (Grill *et al*., 2015; Petts, 2018). Regulations by the dam are responsible for wide range adjustment of riverbank and channel. The most common response of rivers to regulated flow due to damming includes; (i) enhance erosion, (ii) declined sediment load which accelerates entrainment of channel bed and riverbank material and leads to channel incision, (iii) substantial reduction of sediment delivered , (iv) constant wetting of lower riverbank surfaces due to day to day flow fluctuations associated with damning regulations leading to greater erodibility (Williams & Wolman, 1984).

River Kahang was a free-flowing river before the construction of Kahang dam for water supply purposes, the presence of the dam will cause adjustments downstream due to impoundment of water. The impoundment will, in effect, substantially reduce the flow and sediment flux due naturally downstream, the river will tend to attain equilibrium from this imbalance, which may result in near-bed and riverbank erosion.

The dam effect downstream Kahang dam is already visible as part of the riverbank is seen to be eroding. Some of the eroded segments of the riverbank is shown in Figure 1.2 and 1.3 respectively. In the case of Figure 1.3 it is close to one of the transect where riverbank erosion rate is measured.

Figure1.2: Eroding riverbank downstream Kahang Dam

Figure1.3: Eroding riverbank near erosion measurement transect

Previous research has provided means of assessing and predicting riverbank erosion, for instance, Rosgen (2001) developed a framework for predicting annual sediment yield of streambanks by fitting an empirical model to some morphological parameters. The framework is known as The Banks Assessment of Nonpoint-source

Consequences of Sediment (BANCS) consisting of primarily bank erodibility hazard index (BEHI) and near-bank shear stress index (NBS). These parameters are used to estimate the average erosion rate of a given riverbank. BANCS is a predictive tool in the form of a graphical framework which is modelled using physical parameters namely; bank height, bank slope, root density, root depth, bank materials, vegetation cover, stratification and the ratio of maximum channel depth to mean channel depth. The model can be calibrated using the measured erosion rate over a period. This method is considered practicable and used by river restoration practitioners; however, it has a few drawbacks; its over-reliance on visual estimations to quantify root density. Secondly, the model developed from the method is statistically deficient as weights are arbitrarily allocated to the parameters based on Rosegen extensive field experience. Finally, the method only takes into consideration morphological, physical parameters even though literature has shown that soil physical characteristics and hydrological variables also enhance erosion.

Some other erosion indexes are developed based on soil erodibility alone. For example, Bouyoucos (1962) developed an erodibility index based on soil physical characteristics. Similarly, Zainal Abidin & Mukri (2002) expanded the erodibility index by Bouyoucos (1962) to suit peculiarities of Malaysian erodibility risks. The index was named after Roslan and Mukri and known as ROM scale, which is based on soil characteristics grading to indicate the degree of soil erodibility tragedies. Furthermore, the ROM scale was used as a basis for creating a riverbank assessment index for the Langat River in Selangor Malaysia (Zainal Abidin *et al*., 2017). Applicability of the ROM scale is straight forward and easy, but the major drawback of the index is its inability to consider any hydrological factor that may be responsible for causing riverbank erosion.

Several researchers have developed equations and methods of predicting riverbank erosion and its severity along river corridors. The use of statistical methods avails researchers the ability to use several factors or variables that influence riverbank erosion in developing prediction models with reliable predictions, i.e. (Lawler, 1986; Varouchakis *et al*., 2016).

The assessment of the effect of a dam downstream a river concerning sediment concentration and riverbank erosion is quite complex. This process involves the complexities of both hydrological and the site-specific variables. The development of prediction models for sediment concentration and riverbank erosion continues to be a concern to hydrologist and engineers in Malaysia and the world at large. Most existing erosion prediction index is based mainly on soil erodibility or morphological parameters. Therefore, the main objective of this study is to develop a riverbank erosion index for downstream Kahang Dam.

1.3 Objectives of the research

This research embarks on the following objectives to:

i. Develop sediment rating curve and compare with ANN and NNETAR suspended sediment concentration prediction models.
ii. Measure bank erosion within the research area using the erosion pins technique.
iii. Develop a riverbank erosion index as a prediction tool for riverbank erosion.

1.4 Scope of the research

There have been difficulties in past research works on evaluating rivers and streams downstream dams considering the effects caused by flow regulation and sediment entrapment, which give rise to geomorphic changes, i.e., riverbank erosion. The scope of the research was to focus on the effects of Kahang Dam downstream Kahang River. Gauging stations were selected, and field measurements conducted downstream the dam. Three gauging stations were used to monitor sediment concentration rates and river flow. While four transects were also monitored to evaluate the riverbank erosion and or deposition rate. The investigation focuses on three main components; first, sampling locations were identified and field measurement (i.e. erosion and stream flow measurements, sediment and soil particles samples) taken over the sampling period (January 2017 to January 2018). Secondly, samples taken from the field that requires further processing in the laboratory were tested. The suspended sediment samples collected were processed using the evaporation method to deduce the sediment concentration, bed materials were sieve analysed and classified according to BS1377-2, and the hydrometer test was carried out on the riverbank materials to classify the soil physical properties based on BS1377-2. The results obtained were used to generate sediment rating curve equation and machine learning prediction models (ANN and NNETAR) and their prediction ability compared. Also, a riverbank erosion index was developed for the research area. This index was developed combining riverbank soil properties (gravel, sand, clay and silt) and hydrological parameters (rainfall, mean wind speed and discharge). To avoid multicollinearity between the variables the principal component analysis was used, five variables were chosen, i.e., sand, clay, silt, rainfall and discharge. Multiple linear regression analysis (best subset regression method) was used to develop the equation. The best performing model selected has a combination of sand, clay and discharge as predictors. The erosion index developed was classified into five rating class, which is low, moderate, high, very high and critical. This rating can be used to classify the severity of the riverbank erosion rate predicted.

1.5 Significance of the research

The primary goal of this research is to provide an Riverbank Erosion index (R_bEI) that can estimate riverbank erosion rates and sediment concentration estimation models for downstream Kahang Dam using statistical and machine learning methodology, respectively. The R_bEI developed for the study area is expected to serve as a means of predicting the riverbank erosion rate and can be extrapolated to similar hydro-physiographic locations. Reliable and quick sediment concentration estimation will assist in the development of catchment sediment budget. Concerning remediations, the R_bEI can be used to predict riverbank retreat rates and classify the severity of the riverbank retreat based on the estimates provided by the R_bEI. These estimates can form part of the study area bases for analysing and adopting river stabilisation and restoration design, which will be of importance to the dam operators and relevant Malaysian department and agency in making informed decisions regarding early warnings on the riverbank stability. Also, this may give an insight into the effect of situating a dam on a river in terms of sediment supply and riverbank erosion. Finally, measuring riverbank erosion rates from different riverbanks across the country will only strengthen the limited scientific knowledge and further research in similar areas.

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